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The Bilateral Field Advantage on Verbal and Nonverbal Matching Tasks

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Abstract

Three experiments examined the bilateral field advantage (BFA) on both verbal and nonverbal matching tasks. The goal of the experiments was to determine which conditions would maximize the size and reliability of the BFA, and thus enhance its value as a possible diagnostic tool to assess callosal dysfunction. In Experiment 1, 27 right-handed college students performed two matching tasks (order of tasks varied across subjects; dots-letters, letters-dots, or letter and dot trials randomly interleaved). Results revealed a verbal BFA in all task order conditions ($p<.01$), but a significant nonverbal BFA only in the interleaved condition ($p<.01$). Experiments 2 and 3 reproduced the interleaved condition with different parameters. In both experiments the verbal BFA was significant ($p<.01$), but nonverbal BFA was significant only when four-dot patterns were used ($p<.05$). Results suggest the interleaved presentation of verbal and nonverbal stimuli is a reliable method of measuring the BFA.

Despite the fact that the brain is made up of two distinct hemispheres with specialized abilities (Hellige, 1990), the brain acts in a unified manner. This collaboration between hemispheres is possible because they are cross-connected through the forebrain commissures, primarily the corpus callosum. Past research, described by Jeeves (1991), on the sharing of information across the hemispheres, has found a BFA. "This refers to the finding when two stimuli, normally visual, have to be compared and a judgment made whether they are the same or different; if one stimulus is sent separately to each hemisphere the task is accomplished faster and with fewer errors than if both stimuli go to one hemisphere" (Jeeves, 1991, p. 7). Although a few exceptions have been reported (Liederman, Merola, & Martinez, 1984; Schmitz-Gielsdorf, Willmes, & Hartje, 1988) most studies using simple letter pairs or dot-pattern pairs have found that bilateral presentations of stimuli produce faster and more accurate responses than unilateral presentations of stimuli (Banich & Belger, 1990; Belger & Banich, 1992; Coney, 1985; Davis & Schmit, 1973; Ludwig, Jeeves, Norman, & DeWitt, 1993; Norman, Jeeves, Milne, & Ludwig, 1992; Sereno & Kosslyn, 1991). On the basis of these results, Jeeves has suggested that the bilateral field advantage (BFA) is a good measure of informational transfer through the corpus callosum and therefore of the hemispheric interactions that characterize a fully functioning, unified brain.

Recent research has produced evidence of abnormal interhemispheric transfer in schizophrenia, dyslexia, multiple sclerosis, and the normal aging process (Burnison, Larson, & Brown, 1992, 1993; Hellige, 1990). If a robust BFA for both letter pairs and dot pattern pairs could be attained in a single testing session, then a reliable index of the overall BFA could be developed for use in clinical assessment of populations in which abnormal hemisphere interactions may occur. The present series of three experiments was designed to test, refine, and, if needed, redesign the methods previously used to measure the BFA.

Almost all the previous studies of the BFA have used a single stimulus type (letters, words, geometric shapes, or dot patterns). A study by Zenhausern (cited in Schmitz-Gielsdorf et al., 1988) appears to be the only study that combined two stimulus types; subjects showed a bilateral advantage when word trials and shape trials were randomly interleaved, but not when the two types of trials were presented in separate blocks. Therefore, Experiment 1 included both blocked and interleaved conditions to determine whether interleaved presentation would yield a more robust BFA for both verbal and spatial tasks. All three experiments contained a letter-matching task (using pairs of letters drawn from the set AaBb) to target the left (verbal) hemisphere and a dot-pattern matching task (consisting of four or five dots arranged in an imaginary 3 x 3 grid) to target the right (spatial) hemisphere. The choice of stimuli was based on previous research paradigms that elicited the strongest BFA (Banich & Belger, 1992; Ludwig et al., 1993; Norman et al., 1992).

Experiment 1

Method

Subjects. Thirty-four students from introductory psychology classes participated in this study. All subjects were in the 18-21 year age range, of European-American descent, and attended Hope College in Holland, Michigan, a private liberal arts college consisting of 2,600 students. All participating students had normal or corrected to normal vision, and all received course credit for their participation. Only the data from the 27 right-handed subjects (16 females and 11 males) were included in the statistical analyses to eliminate any possible confound with handedness.

Design and Materials. This experiment used a 3 x 2 x 2 x 4 mixed factorial design. The first independent variable, Block Condition, was a between-subjects factor with three levels: block type 1 (dot trials before letter trials), block type 2 (letter trials before dot trials), and interleaved (dot and letter trials interleaved at random). There were three within-subjects factors: Stimulus Type (dot patterns, letters), Response Type (match, no-match--see Figure 1), and Screen Position (left visual field, right visual field, bilateral horizontal, bilateral diagonal--see Figure 2). The dependent variables were accuracy and reaction time recorded in milliseconds.

All stimulus materials were generated on a 386sx microcomputer system and presented using a VGA monitor. The stimuli included a fixation point (which was a small circle in the middle of the screen) and two types of targets. The targets were either letters (upper and lower case "A" and "B") or dot patterns formed with four diamond-shaped figures (character four from the IBM character set) arranged in an imaginary 3 x 3 matrix.

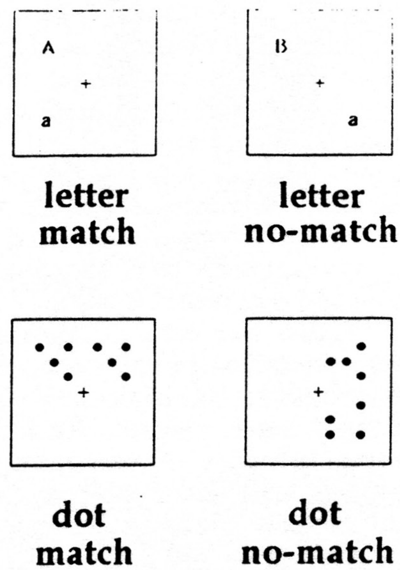

Figure 1. Sample stimuli illustrating two response conditions.

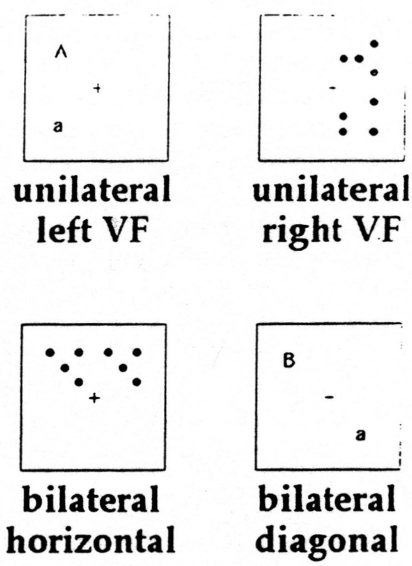

Figure 2. Sample stimuli illustrating four Screen Positions.

The letter targets were presented at a 4.2 degrees visual angle to the left or right of the fixation point and 4.0 degrees above or below the fixation point. Each target dot pattern was centered around the target letter locations. The imaginary square formed by the four target locations allowed the following presentation conditions: left visual field and right visual field, both of which used unilateral presentation with one target above the other; bilateral horizontal, with one target in each visual field and both targets arranged horizontally above or below fixation; and bilateral diagonal, with one target in each visual field and targets arranged diagonally with one target above fixation and one below fixation.

Hand use was counterbalanced across subjects, with half using their left hand to indicate a match and half using their right hand. Block Condition, the between-subjects factor, was also counterbalanced across subjects. One third of the subjects received 160 dot pattern trials followed by 160 letter trials, another third received 160 letter trials followed by 160 dot trials, and the remaining third received 160 dot trials and 160 letter trials interleaved at random.

Each trial began with a 1000 ms preparation interval in which only the fixation point was on the screen. This was followed by a warning signal (the fixation point disappeared for 200 ms) and a random delay of 50 to 100 ms. The target pair was then presented with an exposure duration of 170 ms--12 raster-scan frames of 14.2 ms each. (The 24 practice trials used a longer exposure duration beginning at 36 frames and decreasing one frame on each trial.) The subject then pressed a shift key to respond. The computer program recorded the subject's response and reaction time. Responses faster than 100 ms or slower than 2000 ms were scored as errors and were not included in the statistical analyses.

Procedure. Subjects were tested in a computer laboratory room in three groups of 9, 12, and 13 people. The subjects first completed a Handedness Inventory and then used a 60 cm string to determine the appropriate viewing distance from the screen. Each subject was asked to maintain this distance throughout the experiment.

The subjects were instructed to stare at the fixation point and respond to the stimulus pair as soon as they could decide whether or not both stimuli were the same. It was impressed upon the subjects that speed of response, as well as accuracy, was important, as was concentrating on the fixation point at all times. The subjects then completed 24 practice trials followed by 320 test trials in four blocks of 80 trials each, with a 20 second rest period between sets. During the rest periods, subjects were told they should rest their eyes, stretch, and re-check the distance from their eyes to the screen, but should not disturb the person next to them. At the end of the 30 min session, subjects were debriefed and dismissed.

Results

Mean reaction time and percent correct scores were computed for each cell of the design for each subject. Then a 3 x 2 x 2 x 4 mixed design analysis of variance was performed on each score, with Block Condition (blocked or interleaved) as a between-subjects factor and Response Type (match or no match), Stimulus Type (letters or dots), and Screen Position (unilateral right or left, bilateral horizontal or diagonal) as within-subjects factor.

Reaction Time. The main effect of Block Condition was not significant. A significant main effect was found for Response Type, $F(1,24) = 20.02$, $p < .05$. Subjects were faster for match trials (M = 727 ms) than for no match trials (M = 774 ms). The main effect of Stimulus Type was not significant. The main effect of Position was significant, $F(3,24) = 8.82$, $p < .05$. In order to check for the BFA, a series of planned comparisons tested the average of unilateral left and right against the average of bilateral horizontal and diagonal. Planned comparisons (collapsing across stimulus types) found bilateral trials (M = 740 ms) to be significantly faster ($p < .01$) than unilateral trials (M = 761 ms)--a significant overall BFA. The interaction between Stimulus Type and Position was not significant. For letters only, planned comparisons on the Position factor (p < .05) found a significant BFA of 27 ms. The 16 ms BFA for dots only, although not as impressive, was also significant (p < .05; see Figure 3).

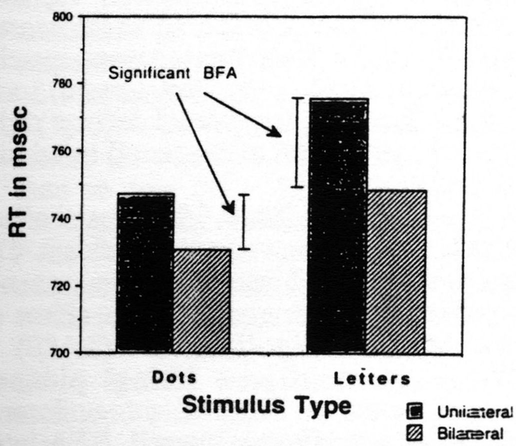

Figure 3. Response speed by stimulus Type in Experiment 1.

There was a significant interaction effect between Response Type and Position, $F(3,72) = 3.3$, $p < .05$. Although there was a large difference between match and no match on unilateral trials, this difference diminished on the bilateral trials. There was a significant 4-way interaction for Condition x Response Type x Stimulus Type x Position, $F(6,72) = 2.479$, $p < .05$. Simple effects tests (p < .01) revealed that the BFA for letters was significant in all three block conditions, but that the BFA for dots was significant only in the interleaved condition (see Figure 4).

Accuracy. The main effect of Block Condition was not significant. A significant main effect was found for Response Type, $F(1,24) = 13.64$, $p < .05$. No match trials were more accurate (M = 86%) than match trials (M = 79.8%). There was a significant main effect of Stimulus Type, $F(1,24) = 12.58$, $p < .05$. Subjects' responses for letters (M = 85.4%) were more accurate than for dots (M = 80.4%). The main effect of Position was significant, $F(3,72) = 3.99$, $p < .05$. Planned comparisons (collapsing across stimulus types) found subjects to be more

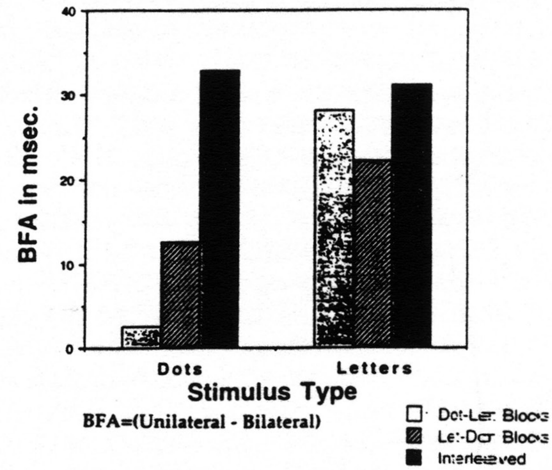

Figure 4.* *Bilateral field advantage by Block Condition and Stimulus Type in Experiment 1.

accurate (p < .05) when stimuli were presented bilaterally (M = 83.7%) than unilaterally (M = 81.9%). There was a significant interaction between Stimulus Type and Position, $F(3,72) = 3.51$, $p < .05$. Planned comparisons on the Position factor (p<.05) found a significant BFA for letters only, but not for dots only. Unilateral letter trials (M = 83.6%) were less accurate than bilateral letter trials (M = 87.4%).

Discussion

The goal of this experiment was to obtain a robust BFA for both verbal and nonverbal stimuli. Three different block conditions were used to determine which combinations of stimulus type and presentation conditions would maximize the size and reliability of the BFA, and thus enhance its value as a possible new diagnostic tool for the assessment of callosal dysfunction.

The results revealed a significant BFA for the letter matching task in all conditions, which confirms previous research (Banich & Belger, 1992; Coney, 1985; Ludwig et al., 1993). The results for the dot pattern matching task were mixed: the BFA for dots was significant *only* in the interleaved condition. The pattern of results suggests that the size of the BFA on the dot pattern task is influenced by the presence of letter matching trials, either preceding or surrounding the dot trials. That is, when the dot trials came first in a single block, the BFA for dots was very small (2.6 ms) compared to the significant BFA for letters (28.2 ms); when the dot trials followed a block of letter trials (yielding a significant BFA of 22.2 ms for letters), the BFA for dots increased to 12.7 ms (but was still not significant). When the dot trials were randomly interleaved with letter trials, both tasks yielded significant BFAs of comparable size (dot BFA=33 ms, letter BFA=31.3 ms). Performance on the dot pattern task was consistent with Zenhausen's findings (cited in Schmitz-Gielsdorf et al., 1988) that a BFA is best produced by interleaving stimuli presentations. The results of Experiment 1 suggest that, if both a letter matching task and a dot pattern matching task are combined in one session, the BFA may only occur when the stimulus types are interleaved.

Experiment 2

The results of Experiment 1 clearly point to the interleaved condition as producing the most robust BFA for both dots and letters. However, these results were obtained from only nine subjects. The small number of subjects in each block condition leaves open the possibility that the results could be an artifact of subject selection. A second experiment was thus designed to repeat the interleaved condition with a larger group of subjects.

Method

Subjects. There were 41 subjects, 18 male right handed and 23 female right-handed subjects. Experiment 2 was similar to the first study, with four exceptions: the fixation point was a plus sign (not a circle), the exposure duration of the target pair was 198 ms (not 170 ms), and there were 32 practice trials (not 24). Finally, all 41 subjects received the 160 dot trials and 160 letter trials randomly interleaved.

Results

Mean reaction time and percent correct scores were computed for each cell of the design for each subject. A 2 x 2 x 4 repeated-measures analysis of variance was performed on each of these scores, with Response Type (match or no match), Stimulus Type (dots or letters), and Screen Position (unilateral left or right, bilateral horizontal or diagonal) as within-subjects factors.

Reaction Time. The main effect of Response Type was not significant. The main effect of Stimulus Type was not significant. The overall main effect of Position was significant, $F(3,120) = 39.93$, $p < .01$. Using planned comparisons of bilateral vs. unilateral trials, a significant overall BFA was found, $F(1,40) = 106.08$, $p < .01$, with the bilateral trials (M =746 ms) faster than the unilateral trials (M = 788 ms). There was a significant interaction effect between Stimulus Type and Position, $F(3,120) = 15.28$, $p < .01$. Planned comparisons on the Position factor revealed a significant BFA for both dots only, $F(1,40) = 7.05$, $p < .05$, and for letters only, $F(1,40) = 120.26$, $p < .01$. Letter trials (M = 67 ms) had a larger overall BFA than dot trials (M = 17 ms) [see Figure 5]. There was also a

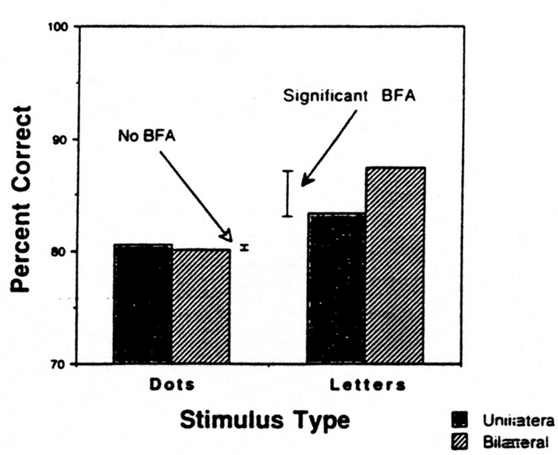

Figure 5. Accuracy by Stimulus Type in Experiment 1.

significant interaction effect between Response Type and Stimulus Type $F(1,40) = 8.62$, $p < .01$. No-match responses were faster for dots ($M = 756$ ms) than for letters ($M = 787$ ms), but match responses were faster for letters ($M = 755$ ms) than dots ($M = 769$ ms).

Accuracy. The main effect of Response Type was significant, $F(1,40) = 9.86$, $p < .01$. No-match responses were more accurate ($M = 88.5\%$) than match responses ($M = 80.9\%$). The main effect of Stimulus Type was also significant, $F(1,40) = 16.7$, $p < .01$. Responses to letters ($M = 87.2\%$) were more accurate than to dots ($M = 82.2\%$). The overall main effect of Position was significant, $F(3,120) = 7.93$, $p < .01$. Planned comparisons of bilateral vs. unilateral trials found a significant overall BFA, $F(1,40) = 22.09$, $p < .01$. Bilateral trials ($M = 86.2\%$) were more accurate than unilateral trials ($M = 83.2\%$). There was also a significant interaction effect between Stimulus Type and Position, $F(3,120) = 3.32$, $p < .05$ (see Figure 6). Planned comparisons on the Position factor revealed a significant BFA for letters, $F(1,40) = 41.8$, $p < .01$, but not for dots. The overall BFA for letters ($M = 4.8\%$) was larger than for dots ($M = 1.4\%$). A significant interaction effect was found between Response Type and Stimulus Type, $F(1,40) = 10.62$, $p < .01$. Dots ($M = 75.6\%$) were less accurate than letters ($M = 86.2\%$) for match, but dots ($M = 88.7\%$) were more accurate than letters ($M = 88.2\%$) for no-match.

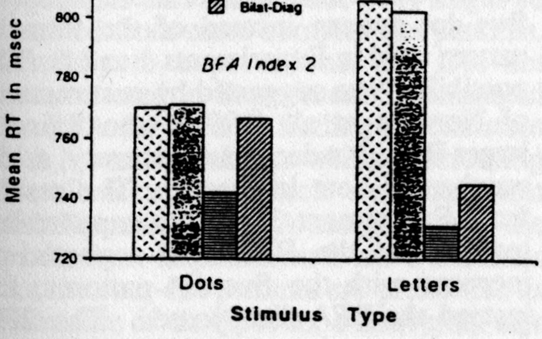

Figure 6. Stimulus Type by Position in Experiment 2.

Discussion

The goal of the second experiment was to reproduce the results of the interleaved condition from Experiment 1, particularly the finding of a significant BFA for both dots and letters, to strengthen the hypothesis that the interleaved condition is the best measure of the BFA and the most applicable for clinical use. This experiment found the same pattern of results as Experiment 1. However, the size of the BFA for the dot task was not as similar to the size of the BFA for the letter task as was found in Experiment 1 (see Figure 4).

Although the BFA for the dot task was significant in the second experiment, it was smaller than in Experiment 1. One possible explanation for this decrease was that overall reaction times were faster in Experiment 2, perhaps suggesting that the four-dot task was too easy to produce a robust BFA. Norman et al. (1992) found a larger BFA with six-dot patterns than with four-dot patterns, so a third experiment was designed to test whether a slightly more complex set of dot patterns would yield a larger BFA in the interleaved condition.

Experiment 3

The goal of Experiment 3 was to determine whether the nonverbal BFA could be increased by using a more complex set of stimulus patterns. To answer this question, Experiment 3 substituted five-dot patterns for the four-dot patterns previously used in Experiments 1 and 2. This five-dot pattern presumably increased the difficulty of the task while retaining the basic characteristics of Experiment 2.

Method

There were a total of 18 subjects, 5 male right-handed and 13 female right-handed subjects. Experiment 3 was identical to Experiment 2, except for the substitution of the five-dot patterns for the four-dot patterns.

Results

A 2 x 2 x 4 repeated-measures analysis of variance was performed on mean reaction time and percent correct scores as computed for each cell of the design for each subject. Within-subject factors were Response Type (match or no match), Stimulus Type (dots or letters), and Screen Position (unilateral left or right, or bilateral horizontal or diagonal).

Reaction Time. The main effect for Response Type was not significant. The main effect for Stimulus Type was also not significant. There was a significant main effect for Position, $F(3,51) = 3.11$, $p < .05$. Planned comparisons of bilateral vs. unilateral trials found a significant overall BFA, $F(1,17) = 5.63$, $p < .05$. Bilateral trials were faster (M = 801 ms) than unilateral trials (M = 823 ms). The interaction between Stimulus Type and Position was also significant, $F(3,51) = 4.1$, $p < .05$. Planned comparisons on the Position factor revealed a significant BFA for letters, $F(1,17) = 18.63$, $p < .01$, but not for dots (see Figure 7). The overall BFA for letters (M = 44 ms) was much larger than the BFA for dots (M = 1 ms). A significant interaction effect was found between Response Type and Stimulus Type, $F(1,17) = 5.66$, $p < .05$. Responses to the dots (M = 827 ms) were slower than letter responses (M = 798 ms) for match, but dot responses (M = 792 ms) were faster than letter responses (M = 831 ms).

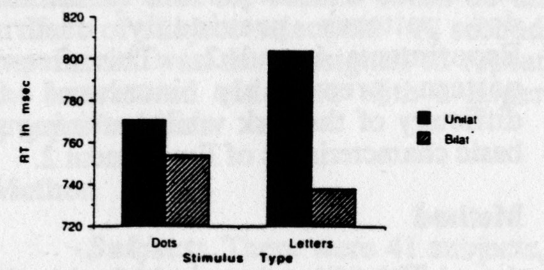

Figure 7. Response speed by Stimulus Type in Experiment 2.

Accuracy. The main effect for Response Type was significant, $F(1,17) = 6.58$, $p < .05$. No-match responses (M = 85.4%) were more accurate than match responses (M = 77.2%). The main effect for Stimulus Type was also significant, $F(1,17) = 15.24$, $p < .01$. Responses to letters (M = 85.7%) were more accurate than dot responses (M = 76.9%). There was a significant main effect for Position, $F(3,51) = 6.33$, $p < .01$. Planned comparisons of bilateral vs. unilateral found a significant overall BFA, $F(1,17) = 12.43$, $p < .01$. Bilateral trials (M = 83.4%) were more accurate than unilateral trials (M = 79.2%). The interaction effect between Response Type and Position was significant, $F(3,51) = 3.12$, $p < .05$. Planned comparisons on the Position factor revealed a significant BFA for dots, $F(1,17) = 8.94$, $p < .01$, but not for letters! The overall BFA for dots (M = 6%) was larger than for letters (M = 2.5%) (see Figure 8).

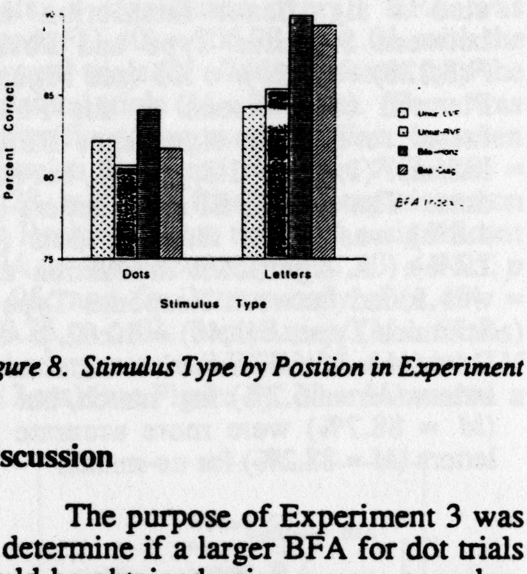

Figure 8. Stimulus Type by Position in Experiment 2.

Discussion

The purpose of Experiment 3 was to determine if a larger BFA for dot trials could be obtained using a more complex, five-dot pattern instead of the four-dot pattern used in Experiments 1 and 2. This possibility was suggested by past research of Norman et al. (1992) who found a larger BFA, but decreased accuracy, as the number of dots increased. The results from Experiment 3 did not support this hypothesis; the BFA was expected to increase with the five-dot patterns, but instead the BFA disappeared. The BFA for the letter task remained large, as would be expected, but the BFA for the five-dot task was no longer significant. Accuracy also decreased with the five-dot pattern, which is congruent with the findings of Norman et al. The results from Experiment 3 point to the four-dot task as a better measure of the BFA for spatial stimuli than the five-dot task.

General Discussion

The overall goal of these experiments was to develop and refine a set of matching tasks that would yield a robust BFA for both verbal and nonverbal stimuli with normal subjects, and thus could be clinically useful as a possible diagnostic tool to assess callosal dysfunction.

In all three experiments and under all conditions, the letter task yielded a robust BFA, confirming its reliability as a measure of interhemispheric verbal processing. This finding was consistent with previous research (Banich & Belger, 1990; Belger & Banich, 1992; Coney, 1985; Ludwig et al., 1993).

In Experiment 1, the dot task produced a significant BFA only in the interleaved condition (see Figure 4). Experiment 2 reproduced this finding with a larger number of subjects, yielding a significant BFA for both letters and dots with the interleaved presentation. However, the BFA for dots was smaller in Experiment 2 than it was in Experiment 1. This raised questions about the difficulty of the dot pattern task. Since Norman et al. (1992) had found the BFA to increase as the dot patterns grew more complex (by increasing the number of dots in the pattern), Experiment 3 tested the hypothesis that a larger dot BFA might be obtained from more complex dot patterns. Contrary to expectations, the five-dot patterns used in Experiment 3 eliminated the BFA for dots (a finding inconsistent with Norman et al.), as well as decreasing overall accuracy (which was consistent with Norman et al.). A comparison of the results from Experiments 2 and 3 indicates that the four-dot patterns are preferable as a measure of the BFA for a nonverbal task (see Figure 9).

To develop a standard measure of the BFA that could be useful in clinical application, the tasks should first be reliable predictors of normal callosal function. To determine if the tasks didproduce an appropriate BFA in a

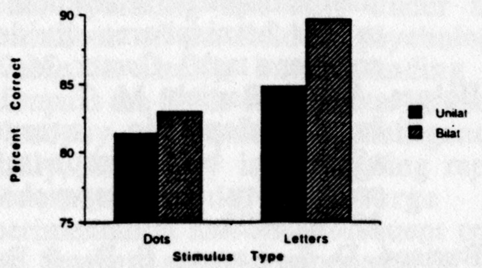

Figure 9. Accuracy by Stimulus Type in Experiment 2.

substantial majority of the subjects in the present experiments (who were presumed to have normal callosal functioning) the BFA for both dots and letters was computed separately for each subject. The proportion of subjects who showed an appropriate BFA on each task, for each experiment, is represented in Figure 10. The results confirm that interleaving the four-dot pattern task and the letter task yields the most reliable individual predictions of normal callosal function.

The results of these three experiments suggest that an interleaved presentation of a letter matching task and a four-dot pattern matching task could be a useful non-invasive behavioral technique to assess callosal functioning in a clinical setting, and could thus contribute to an improved understanding

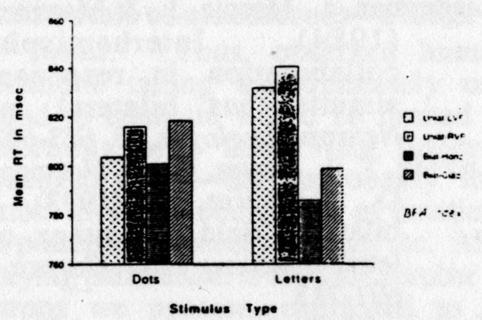

Figure 10. Stimulus Type by Position in Experiment 3.

of the role of callosal dysfunction in dyslexia, schizophrenia, multiple sclerosis, and in the normal aging process.

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